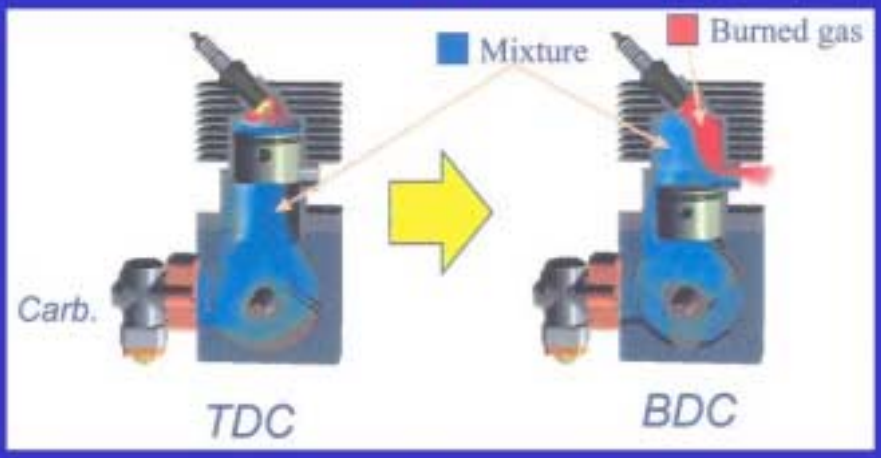
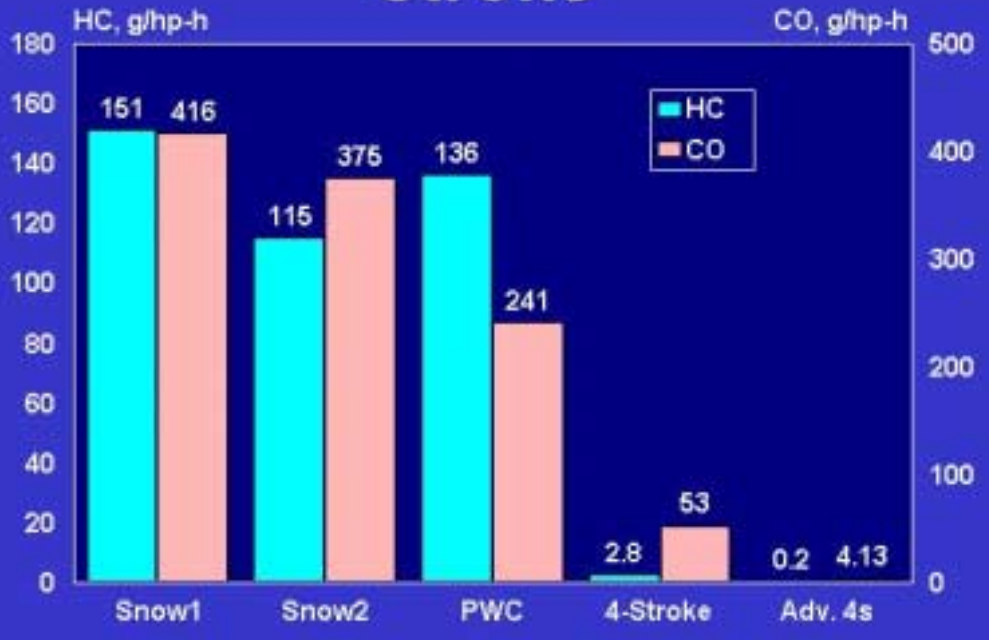
This discussion covers

- Concerns and problems with snowmobile/small engine emissions
- Two-stroke vs 4-stroke engines
- Emissions impacts on air and personal exposure
- What can be done, impacts of bio-based fuels, new technology, Clean Snowmobile Challenge

Design Characteristics

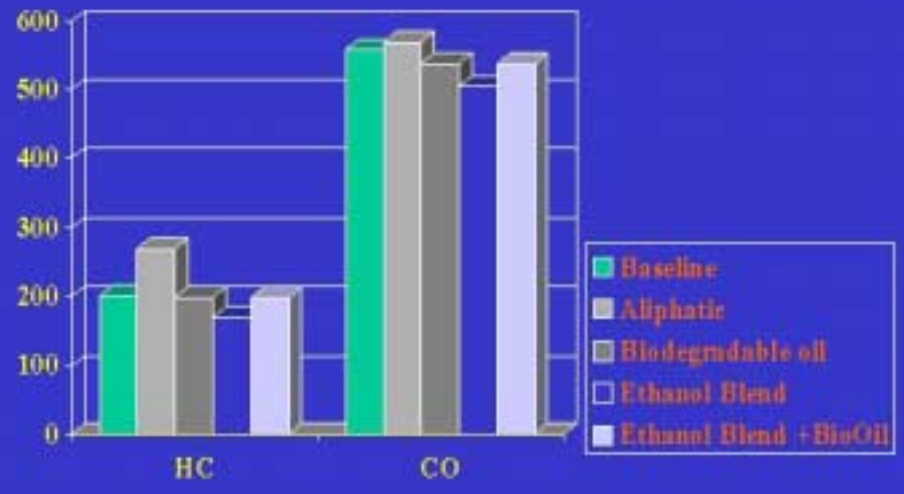


Emissions - 2-stroke vs. 4-stroke



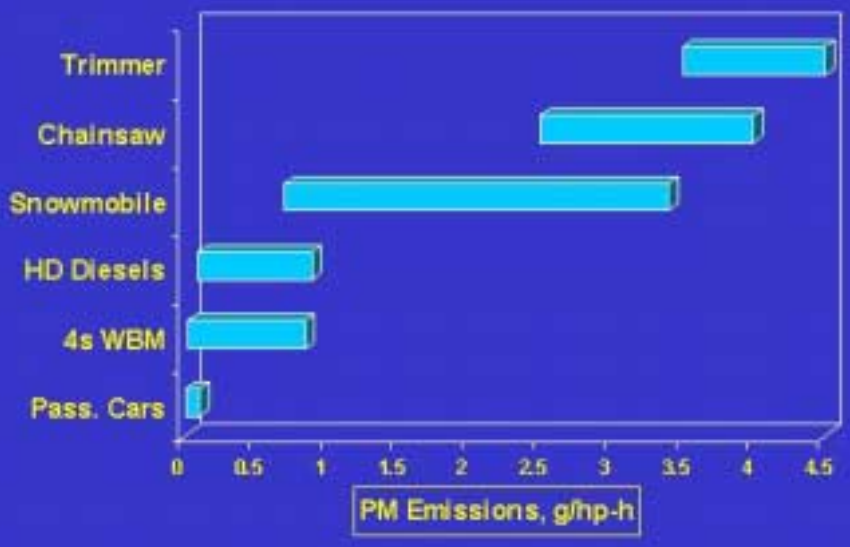
Polaris 488cc 5-Mode Emission Tests

White, Carroll, Haines 1998

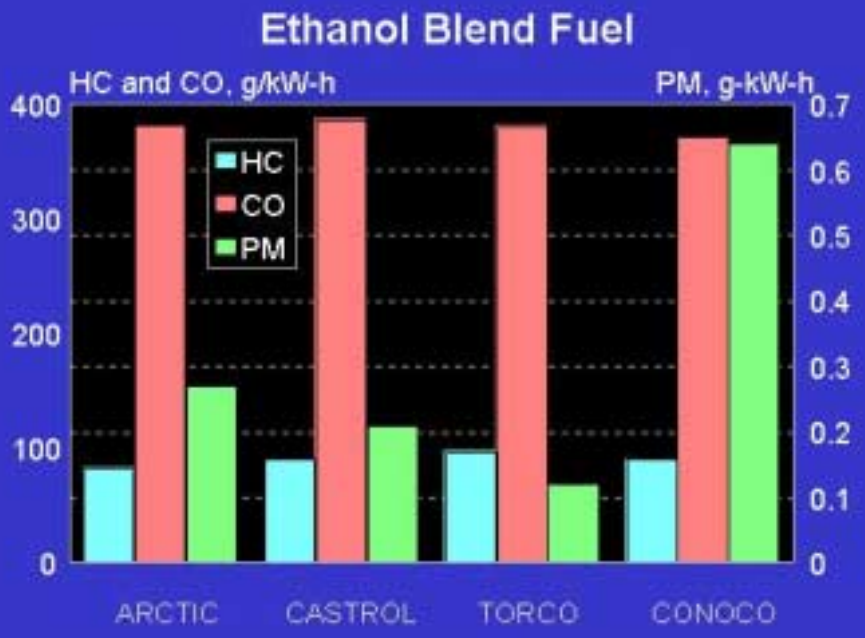


Fuel Consumption - 2s vs. 4s

PM Emissions - 2s vs. 4s

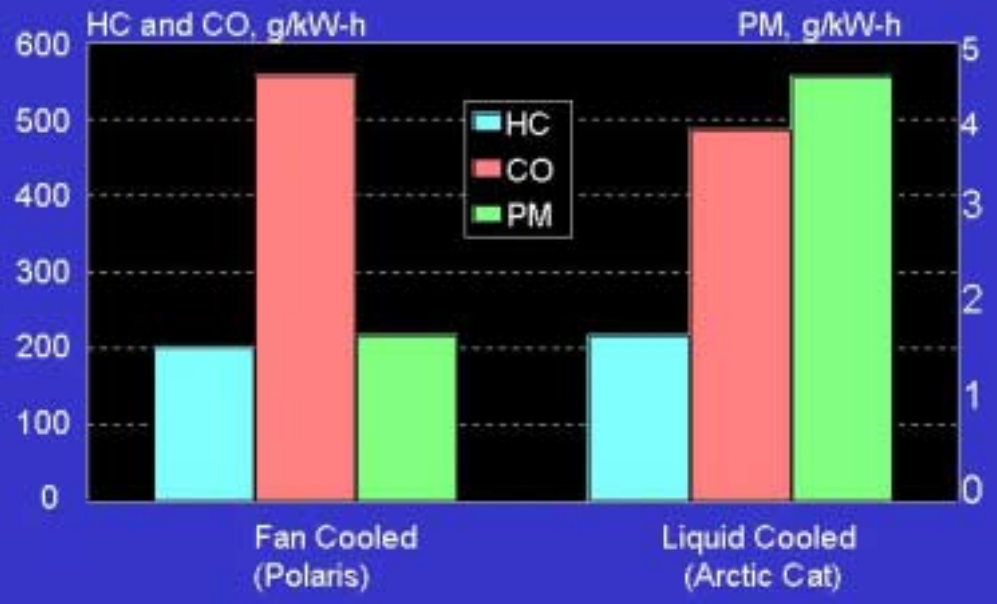


POLARIS MODE 1 LUBRICANT EMISSIONS



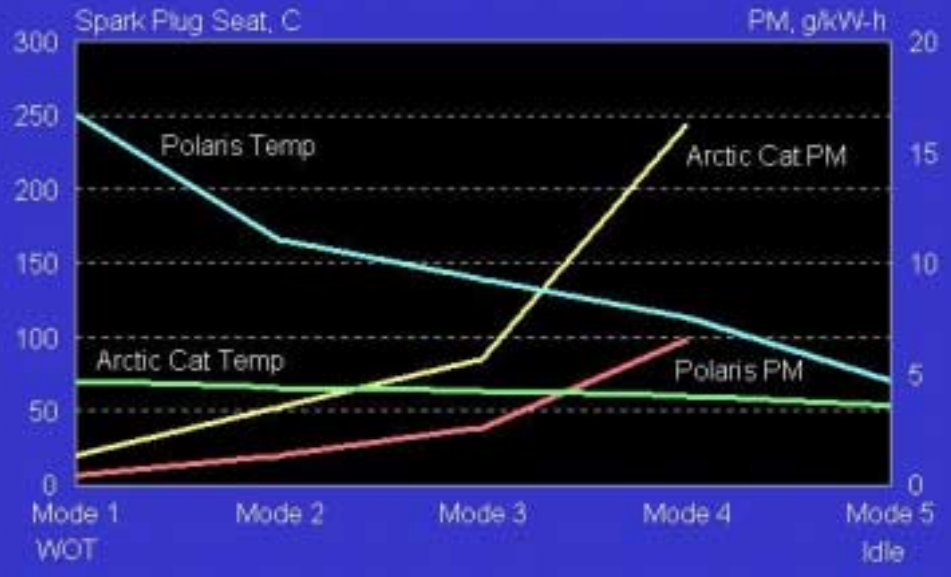
FAN Vs LIQUID COOLED EMISSIONS

Gasoline-ARCTIC Extreme



PARTICULATE EMISSION RATES

Effect of Engine Temperature



Problems and Concerns

- People feeling ill, headaches, irritated eyes
- Visibility and odor
- Noise
- Trail access

Applied research and solutions

- WHAT ARE THE EMMISSION & how to reduce concerns
- Analyze particulate & aerosol
- Southwest Research Institute, Montana State University, University of California--Davis (bioassay)

Applied research and solutions

- MEASURE FIELD EMMISSIONS, IMPACTS
- MDEQ, CO and PM-10 NAAQS monitors
- Dr. G. Bishop, University of Denver (remote tailpipe measurements)
- Dr. G. Ingersoll, USGS (snowpack, runoff)
- Dr. R. Peterson, Dr. B. Tyler, Montana State University (particulate, aerosols, chemical composition, persistence)

Applied research and solutions

- **MEASURE EMPLOYEES' EXPOSURE**
- Dr. Norman Kado, University of California, Davis CA
- OSHA and NIOSH (2/2000 for NPS)
- Dr. L. Fussell (Model operators exposure to CO)

Water Quality Concerns

- Snowpack samples near heavily traveled snowmobile trails (<50 m) correlated with elevated levels of ammonium, sulfate, benzene and other carbon compounds from gasoline combustion raising concerns about water quality.

Water Quality Concerns

- About 20 percent of emissions are semi-volatile
- Most lube oil is emitted partly oxidized

Water Quality Monitoring

- Snowpack samples near heavily traveled snowmobile trails correlated with elevated levels of ammonium, sulfate, benzene and other carbon compounds from gasoline combustion raising concerns about water quality.

Difference between air quality and personal exposure

- Air quality measured by National Ambient Air Quality Standards, an amount and a procedure for collecting the measurements
- Federal CO 1-hr average limit is 35 PPM (MAAQS is 23 PPM)
- Federal CO 8-hr average limit is 9 PPM

Air Quality Concerns

- Snowmobile emissions in congested traffic areas caused air quality concerns
- President's Day Weekend 1999 yielded 8.9 PPM CO 8-hr average at West Entrance YNP (over 900 snowmobiles entering)
- In 2000, 3.5 PPM CO was highest 8-hour average for similar time and number of vehicles

What trail managers can do

- Reduce or avoid congestion (pre-paid passes at entrances, distributed parking at trail heads)
- Have operators limit speed (~15 mph) in areas of conflicting use
- Promote ethanol blend, low emission lube oils--use these in your fleet

Noise Concerns

- Excessive noise can result in permanent hearing loss.
- Studies document hearing loss for persons subjected to 73 decibels of noise for 8 hours a day for 40 years, or when subjected to 85 decibels over a shorter number of years
- Exposure to loud noise (even with ear protection) raises blood pressure

Noise Concerns

- Noise is a factor for snowmobiles: 88 dB 8-hr Avg for kiosk workers (OSHA action level is 85 dB)
- 93 dB for patrol ranger (Feb 2000)
- Non-snowmobiling visitors also exposed.
- NPS turned away "noisey" (80 dB-A) snowmobiles at West Entrance.

Results of U of Denver

- **A 7 percent ethanol blend reduced CO 7% (+/- 4%) in the field**
- **A low-cost, quick, in-field method was developed to measure tailpipe CO, HC, and if needed, NOx or select air toxics.**

Renewable, Alternate Fuels

- **Every million gallons of ethanol blend burned reduces potential emissions of carbon monoxide by 61 tons**
- **Ethanol blend and low emission lube oils in 2-stroke engines reduces emissions of CO by 7 to 11 %, particulates by 25 to 70 %, & hydrocarbons by 16 to 38 %**

Rental Operators Results

- No carburetor freezing
- Significantly reduced engine failure (only 3 due to collision instead of 20-30 a season)
- Eliminated on-trail spark plug changes
- Reduced or eliminated on-trail service calls

Problems and Concerns

- Employees exposed to snowmobile exhaust under stagnant air and traffic congestion experienced pollution at levels that may cause long-term health risks

Air quality vs personal exposure

- Personal exposure refers to compounds in the breathing zone of an individual. For example the air inside a garage would be personal exposure--outside would be air quality.

Air quality vs personal exposure

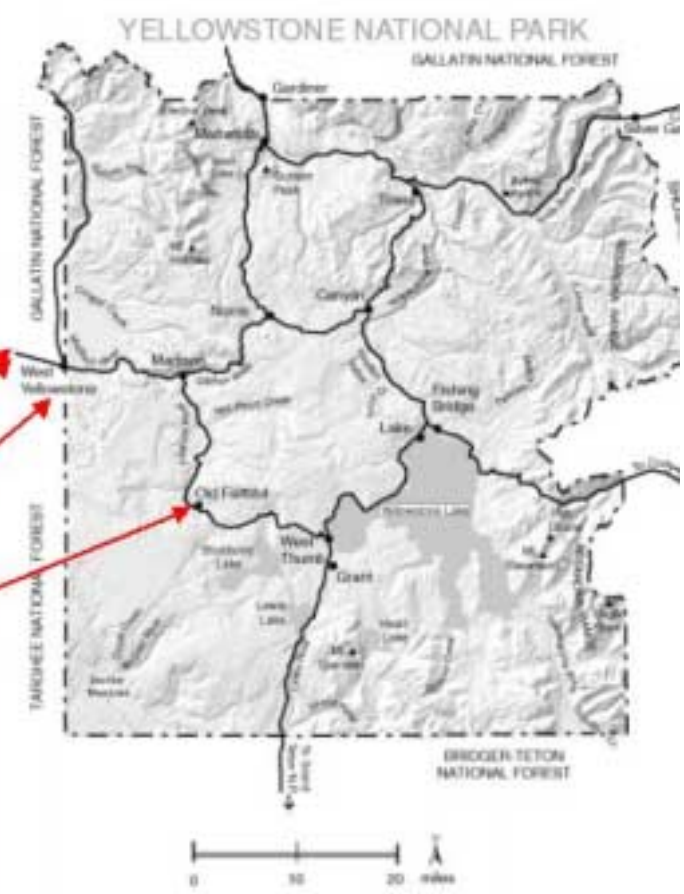
- Personal exposure limits are enforced by the Occupational Safety and Health Administration (OSHA).
- Permissible exposure level (PEL) measurements are made and averaged usually for an 8-hour work shift. Short Term Exposure Limits (STEL) are not to be exceeded at any time.

Occupational Exposure

- OSHA: PEL (8 hr), STEL (15 min)
- NIOSH: REL(8 hr), STEL (15 min)
- ATSDR: MRL

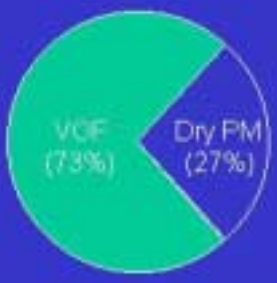
PM-10 Fixed Site Monitoring

Kado et al. 1999



PM Volatile Organic Fraction Analysis

Mineral-based lube



12.4 g PM/hr.

(VOF= 67% lube)

Biosynthetic lube

24.7 g PM/hr.

(VOF= 50% lube)

Results-Occupational Exposure Study

- **Snowmobile particulate matter has a mutagenic activity similar to that of heavy duty diesel engines (per unit mass)**
- **Total mutagenic activity of PM and emissions decreased by approximately 30% using synthetic biodegradable lubes**

Summary and Conclusions

- 2-stroke snowmobile PM composed principally of volatile organics
- Particle diameters typically less than 100 nm (of respirable size)
- Bioassay shows that snowmobile PM is mutagenic, at levels similar to that of diesel PM

Results-Occupational Exposure Study

- Mechanics, toll booth workers, and patrol rangers were exposed to high levels of benzene, toluene, and fine particulate at levels that may cause long-term health risks

Results-Occupational Exposure Study

- The mechanic, five toll booth workers, and patrol rangers were exposed to concentrations of benzene that exceeded both the acute and intermediate Minimal Risk Level (MRL) of the Agency for Toxic Substances and Disease Registry (ASTOR), CDC Atlanta GA

Results-Occupational Exposure Study

- **Volatile Organic Compounds (VOC) found in gasoline were detected in both fixed site and personal exposure samples**
- **NPS mechanic exceeded the NIOSH Recommended Exposure Limit (REL) limit for benzene**

What trail managers can do

- Reduce employee exposures in high traffic area (rotate staff during a shift; stay in enclosed, ventilated areas; limit the number of old technology vehicles)
- Locate potential traffic bottle-necks in areas with good air movement
- Continue to monitor traffic, weather, and emissions at problem areas

Advanced Technologies Applicable to Snowmobiles

Technology	Benefit
• Oxygenated fuels	• Reduced HC and CO
• Low PM lubes	• Reduced PM
• Biodegradable lubes	• Reduced PM impact
• Direct injection	• Reduced HC and PM
• 4-stroke	• Reduced HC, CO, PM
• Electric	• No emissions - quiet

CLEAN SNOWMOBILE CHALLENGE 2000

Student design competition for cleaner, quieter, snowmobiles that meet or beat performance

Clean Snowmobile Challenge 2000

- Seven schools competed
- First Place: State University of New York at Buffalo (UB)
- 4-stroke Polaris engine
- 99.5 % reduction in HC
- 46 % reduction in CO
- 66.8 dB-A

Clean Snowmobile Challenge 2000

- Second Place: University of Waterloo
- 2-stroke Polaris liquid cooled engine
- 95 % reduction in HC
- 50 % reduction in CO

- (quietest, Ecole de Technologie Superieure 66.4 dB-A)

What snowmobilers can do

- Use proper jets and engine tuning for altitude and temperature
- Use ethanol blend to reduce CO and increase power
- Use synthetic, low emission lubes
- Use biodegradable lube to reduce CO and mutagenic potential
- Contact dealers for low-emission vehicles & products, and buy them

Acknowledgements

- US DOE Regional Bioenergy Program
- EPA
- Montana Department of Environmental Quality